

Analyses of tagging data for evidence of decreased fishing mortality for
large yellowtail flounder

Yellowtail Flounder Selectivity Working Group
Tim Miller, Dvora Hart, Steve Cadrin, Larry Jacobson, Chris Legault and
Paul Rago
Northeast Fisheries Science Center, National Marine Fisheries Service, 166
Water Street, Woods Hole, MA 02543 USA

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Introduction

Using the age-structured production model (ASPM) developed by Butterworth and Rademeyer (2008b), Butterworth and Rademeyer (2008a) determined that an assumption of dome-shaped selectivity pattern for instantaneous fishing mortality fit Georges Bank yellowtail flounder (*Limanda ferruginea*) data better than a flat-topped selectivity pattern.

The hypothesis of a strong dome-shaped selectivity pattern across all gear types can be difficult to evaluate since relatively low catches of older fish could be explained either by a dome-shaped selectivity or by actual low abundance of older animals caused by high mortality. Tagging data gives an opportunity to distinguish between these hypothesis, since the actual population of tagged fish at release are known.

Here we perform two analyses of yellowtail tagging data from an ongoing cooperative NMFS tagging study (Cadrin et al. 2007). The first compares expected probability of recovery by age class for tagged fish based on estimates of age-specific fishing mortality by Butterworth and Rademeyer (2008a) with the observed proportions of recoveries (by sex) for different length classes (and approximate corresponding ages) in the yellowtail tagging data. The second analyses fits a simple finite-state continuous-time model (Miller and Andersen 2008; Miller and Tallack 2007) to the yellowtail flounder tagging data to estimate different fishing mortality parameters for fish less and greater than 44 cm at release while also estimated migration and natural mortality rates along with reporting probability and a scalar to adjust fishing mortality in the first month after release, all of which are assumed uniform across the three stock areas.

Comparison of yellowtail tagging recoveries with those expected under dome-shaped selectivity

Here, we use data from recent large-scale tagging experiments on yellowtail flounder to explore the possibility of domed selectivity for these fish.

A simple model for estimating the probability of recapture of a tagged fish

Let F_a , M_a and $Z_a = F_a + M_a$ denote fishing, natural, and total mortality at age a , respectively. Suppose a fish was tagged at age A . Its probability of recapture is:

$$(1) \quad R_A = \frac{F_A}{Z_A} [1 - \exp(-Z_A)] + \sum_{a=A+1}^{\infty} \frac{F_a}{Z_a} [1 - \exp(-Z_a)] \exp\left(-\sum_{\alpha=A}^{a-1} Z_{\alpha}\right)$$

This equation implicitly assumes no tagging induced mortality, but Cadrin et al. (2007) found no evidence of such mortality for these types of tags with yellowtail flounder. Additionally, actual tagging recovery rates may be reduced because some tags are not reported. Both these factors would cause the proportion of tags that are reported recaptured to be less than that calculated in equation (1); if both these factors are independent of age, they would simply reduce R_A by a constant for all ages.

If natural mortalities are constant with age, but fishing mortalities decrease with age because of dome-shaped selectivity, equation (1) predicts that fraction of fish that are recovered will decline as the age of tagging A increases. We illustrate this using the fishing

mortalities and dome-shaped selectivity estimated by Butterworth and Rademeyer (2008) in their base case. They estimated recent (2006) fully recruited fishing mortality for Georges Bank yellowtail flounder to be $F = 0.06$ and rapidly reduced selectivity for ages greater than 4 (Table 1). Estimated recovery rates from tagged fish based on this data drop from 11.5% for 3 year olds to 4.3% at age 5 to 0.9% at age 7 (Table 1 and Figure 1). By contrast, if selectivity (and natural mortality) was flat, then recovery rates would be independent of age.

These predictions can be compared to results of the NMFS cooperative tagging study (Cadrin et al. 2007). Recoveries were roughly constant with age, and for the larger length categories corresponding to older ages, the recovery rate was higher than that predicted from Table 1, even though the Table 1 estimates neglect tagging induced mortality and non-reporting of recoveries, and therefore should overestimate the recovery rate. These data are thus inconsistent with the domed selectivity proposed by Butterworth and Rademeyer (2008a), and instead strongly suggest that selectivity is flat at older ages/lengths.

FSCT model for yellowtail tagging data

A finite-state continuous-time approach for inferring instantaneous migration and mortality rates from different types of tagging studies including tag-recovery are the subject of recent work by Miller and Andersen (2008). Here we apply the statistical method to data from the NMFS cooperative tag-recovery study on yellowtail flounder, but expand the set of states to allow estimation of tag reporting probabilities and account for incomplete mixing of newly released individuals.

The NMFS cooperative study has released over 42,000 yellowtail flounder with disc and data storage tags in the three stock regions (Cape Cod/Gulf of Maine, Georges Banks and Southern New England) between 2003 and 2006. Some fish were released with either high or low-reward tags. No fish were double tagged, but tag shedding is assumed negligible. Over 3000 individuals have been recovered to date, but we consider the end of 2006 as the end-time of the study to reduce problems relating to delay of reporting recovered tags.

States of the process

When the k th tagged fish is released in one of three regions at time $t_{0,k}$ it may at any instant move to one of the other two regions or die due to fishing or natural causes (given fishing activities are occurring). If it dies due to fishing at time $t_{r,k}$ in one of the three regions, it may be reported with probability $\rho < 1$. The tagged fish recovered may not be reported with probability $1 - \rho$. The fish may also remain alive at the time of analysis t_a . As such, there are 12 states that a fish may exhibit (Table 3).

The 12×12 instantaneous rate matrix is

$$\mathbf{A}_\tau = \begin{pmatrix} \mu_{2,\tau} & \rho \mathbf{F}_\tau & (\mathbf{I} - \rho) \mathbf{F}_\tau & \mathbf{M} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

where \mathbf{I} is a 3×3 identity matrix and $\mathbf{0}$ is a 9×3 matrix of zeros. The elements, \mathbf{F}_τ and \mathbf{M} are 3×3 diagonal matrices of instantaneous fishing $((F_{1,\tau}, F_{2,\tau}, F_{3,\tau})^T)$ and natural mortality rates $((M_1, M_2, M_3)^T)$, respectively, for regions 1-3, where $\tau \in \{2003, 2004, 2005, 2006\}$ indexes yearly time intervals. The 3×3 diagonal matrices ρ contains the three regional reporting

probabilities $((\rho_1, \rho_2, \rho_3)^T)$. For individuals released with low-reward tags, $0 < \rho_r < 1$, $r \in \{1, 2, 3\}$ and we assume $\rho_r = 1$ for high-reward tags. The remaining elements contain the instantaneous migration rates and forces of transition from the states along the diagonal,

$$\boldsymbol{\mu}_\tau = \begin{pmatrix} -a_{1,\tau} & \mu_{12} & \mu_{13} \\ \mu_{21} & -a_{2,\tau} & \mu_{23} \\ \mu_{31} & \mu_{32} & -a_{3,\tau} \end{pmatrix}$$

where $a_{h,\tau}$ is the sum of the elements of \mathbf{A}_τ in row h off the diagonal.

To allow for different fishing mortalities of tagged fish k between the time of release $t_{0,k}$ and 1 month later $t_{0,k} + 1/12$ we allow a modification to the fishing mortality matrices in \mathbf{A}_τ . The instantaneous rate matrix for this period is

$$\mathbf{A}_\tau^* = \begin{pmatrix} \boldsymbol{\mu}_\tau & \boldsymbol{\rho}\mathbf{F}_\tau^* & (\mathbf{I} - \boldsymbol{\rho})\mathbf{F}_\tau^* & \mathbf{M} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

where $\mathbf{F}_\tau^* = \boldsymbol{\gamma}\mathbf{F}_\tau$ and $\boldsymbol{\gamma}$ is a 3×3 diagonal matrices of region specific scalars $((\gamma_1, \gamma_2, \gamma_3)^T, \gamma_r > 0)$ to modify fishing mortality for the recent releases. Note that this allows fishing mortality for the first month to be either less than that of other fish ($0 < \gamma_r < 1$) or greater than that of other fish ($\gamma_r > 1$). Also, note that the instantaneous fishing mortality rates (and hence the matrices \mathbf{A}) are allowed to differ between release size classes ($\leq 44\text{cm}$ and $> 44\text{cm}$).

Models and likelihood

Let $Y_k(t) \in S = \{1, \dots, h, \dots, 12\}$ be the state tagged fish k is in at time $t_{0,k} \leq t \leq t_a$. Given a vector of unknown instantaneous rate parameters \mathbf{a} in the instantaneous rate matrix, the likelihood we maximize is

$$(2) \quad \mathcal{L}(\mathbf{a}) = \left\{ P_{Y_k(t_{0,k}), Y_k(t_{r,k}-)} a_{Y_k(t_{r,k}-), Y_k(t_{r,k})} \right\}^{I(Y_k(t_a) \in \mathcal{F})} \times \left\{ \sum_{Y_k(t_{a,k}) \notin \{\mathcal{F}\}}^H P_{Y_k(t_{0,k}), Y_k(t_a)} \right\}^{I(Y_k(t_a) \notin \{\mathcal{F}\})}$$

where $I(Y_k(t_a) \in \mathcal{F})$ is an indicator of whether the animal is in a caught and reported state at time of analysis and $I(Y_k(t_a) \notin \{\mathcal{F}\})$ is an indicator of whether the animal is any other state at time of analysis (Miller and Andersen 2008, eq. 5). The first line in eq. 2 is the product of the probability of being alive in region of recovery just prior to capture at time $t_{r,k}-$ given $Y_k(t_{0,k})$ and the instantaneous rate of capture in the region where recovery occurred. The probability $P_{Y_k(t_{0,k}), Y_k(t_{r,k}-)}$ is the $(Y_k(t_{0,k}), Y_k(t_{r,k}-))$ element of the probability transition matrix, $\mathbf{P}(t_{0,k}, t_{r,k}-)$ and $a_{Y_k(t_{r,k}-), Y_k(t_{a,k})}$ is the $(Y_k(t_{r,k}-), Y_k(t_{a,k}))$ element of the instantaneous rate matrix (\mathbf{A}_τ), such that $t_{r,k}$ is in the corresponding year. The second line in eq. 2 is the probability of being in any of the states not corresponding to capture and reporting at the time of analysis given $Y_k(t_{0,k})$ which is the sum of the elements of the probability transition matrix $\mathbf{P}(t_{0,k}, t_{a,k})$ in row $Y_k(t_{0,k})$ where $Y_k(t_{a,k}) \notin \{\mathcal{F}\}$. See (Miller and Andersen 2008) for how the probability transition matrix is formed from the instantaneous rate matrix.

Results and Discussion

For this preliminary analysis we fit a single model to the yellowtail flounder tagging data where the migration rates, fishing mortality rates, natural mortality rates, non-mixing scalars and reporting probabilities are constant across regions and years, but unique fishing mortality rates were allowed for the larger and smaller length classes. Thus, there were six parameters estimated (Table 4). The main finding here is the lack of a statistically significant difference between fishing mortality rates for the two size classes. However, the natural mortality rate estimate is perhaps unrealistically high as was also found for Atlantic cod by (Miller and Tallack 2007).

References

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Table 1. Fishery selectivity, fishing mortality, total mortality and tagged recovery probability based on the estimated selectivity and fishing mortalities from the base case of Butterworth and Rademeyer (2008a).

Age	Select.	F_a	Z_a	R_a
3	1	0.06	0.26	0.115
4	0.9	0.054	0.254	0.081
5	0.5	0.03	0.23	0.043
6	0.25	0.015	0.215	0.021
7	0.1	0.006	0.206	0.009
8	0.05	0.003	0.203	0.004

Table 2. Length classes (in cm.), mean age at these lengths, based on port samples from 2003-2005, number of recoveries (N) and recovery rates (R) by sex, from the data of Cadrin et al. (2007).

Lengths	AgeFemale	N_{Female}	R_{Female}	AgeMale	N_{Male}	R_{Male}
33-35	2.88	235	0.08	2.93	169	0.07
36-38	3.30	569	0.09	3.46	181	0.05
39-41	3.75	565	0.08	3.95	64	0.05
42-44	4.42	507	0.08	4.43	14	0.10
45-47	5.45	265	0.08	6.00	5	0.08
48-55	7.37	96	0.09	7.00	3	0.09

Table 3. States a tagged yellowtail flounder may exhibit during the time of the study.

State	Definition
1	Alive in Cape Cod/Gulf of Maine
2	Alive in Georges Bank
3	Alive in Southern New England
4	Caught in Cape Cod/Gulf of Maine and reported
5	Caught in Georges Bank and reported
6	Caught in Southern New England and reported
7	Caught in Cape Cod/Gulf of Maine and not reported
8	Caught in Georges Bank and not reported
9	Caught in Southern New England and not reported
10	Dead from non-fishing causes in Cape Cod/Gulf of Maine
11	Dead from non-fishing causes in Georges Bank
12	Dead from non-fishing causes in Southern New England

Table 4. Parameter estimates and approximate 95% confidence intervals.

Parameter	$\hat{\theta}$	CI_L	CI_U
μ	0.045	0.042	0.050
$F_{\leq 44}$	0.131	0.120	0.143
$F_{>44}$	0.137	0.124	0.152
M	1.135	1.099	1.172
γ	3.994	3.827	4.169
ρ	0.644	0.587	0.697

Figure 1. Predicted probability of recovery based on the selectivity and fishing mortality given in the base case of Butterworth and Rademeyer (2008).

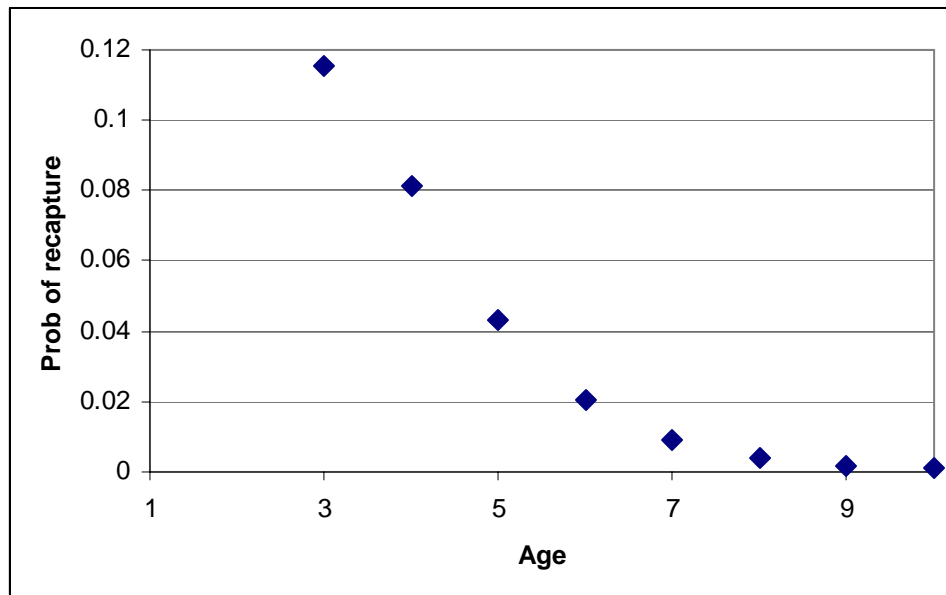


Figure 2. Observed recovery rates of tagged yellowtail flounder of females (filled circles) and males (squares), by length, from Cadrin et al. (2007).

